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Policy scenarios for energy efficiency improvement in industry

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Abstract

We have investigated three policy scenarios, entailing different degrees of commitment to improve energy efficiency to address the energy, economic and environmental challenges faced by the US industry. The scenarios reflect alternative views of the urgency with which policymakers and the American people will view these challenges and the policies they will seek. The industry consumes about 37% of primary energy in the United States, and is expected to grow under business-as-usual conditions. The policy scenarios find energy efficiency improvements from 7% to 17% beyond business as usual by 2020 for the Moderate and Advanced scenarios, respectively. The study demonstrates that there are substantial potentials for further efficiency improvement in the industry. However, an integrated policy framework that accounts for the different characteristics of industrial sector decision-makers, technologies and sectors is needed to achieve these potentials. Published by Elsevier Science Ltd.

Keywords: Energy efficiency; Industry; Policies; Modeling

1. Introduction

The industrial sector is extremely diverse and includes agriculture, mining, construction, energy-intensive industries, and non-energy-intensive manufacturing. In 1997, the industrial sector consumed 37 EJ of primary energy, accounting for 37% of the primary energy consumed in the US that year. Various bottom-up studies have found cost-effective potentials for energy efficiency improvement in the industrial sector (Interlaboratory Working Group, 1997; Energy Innovations, 1997). Many studies identified a wide variety of sector-specific and cross-cutting energy efficiency improvement opportunities. Innovative industrial technologies aim not only to reduce energy use, but also to improve productivity, reduce capital costs, reduce operation costs, improve reliability as well as reduce emissions and improve working conditions. Hence, many of the technologies discussed included in this analysis will improve the productivity of industries, and hence increase competitiveness in a globalizing economy.

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In this paper, we present scenarios for future industrial energy use, based on different assumptions for the US energy policies, using the results of the Scenarios for a Clean Energy Future (CEF) study (IWG, 2000). Following a 1997 study, Scenarios of US Carbon Reductions, the US Department of Energy (US DOE) commissioned an Interlaboratory Working Group to examine the potential for public policies and programs to foster efficient and clean energy technology solutions to these energy-related challenges. This earlier report (Interlaboratory Working Group, 1997) identified a portfolio of technologies that could reduce carbon emissions in the United States to their 1990 levels by the year 2010. The CEF study identifies specific policies and programs that could motivate businesses to purchase the technologies making up its scenarios. A scenario is a way to understand the implications of a possible future through modeling assumptions that reflect the future. By definition, considerable uncertainties exist in all scenario analyses and this is also true for the industrial sector where ever-changing dynamics drive decision-making. Uncertainties in the assumptions affect the final results of the scenarios. However, as it is not always possible to quantitatively estimate the uncertainties and for reasons of presentation, we only present point estimates.

We have used an integrated model to assess the different scenarios in this study. The model is derived from the National Energy Modeling System (NEMS) used by the Energy Information Administration (EIA) to make national energy forecasts. Our model is referred to as CEF-NEMS. In this paper, we first discuss industrial energy use in the US, followed by a discussion of the methodology used in this study. We then discuss the main policies applied in the study and the scenario results. The analytical database for the industrial sector is limited and constrains the ability of modelers to do in-depth analysis in this sector. We end with a discussion on the uncertainties and the further research required.

2. Energy use in the US industry

Final and primary energy use in the US has increased in the past decades, although not constantly. The energy price shocks in the 1970s and early 1980s led to a temporary reduction of total energy use, followed by increasing energy use. Today, the US energy use has surpassed the historical high of the 1970s due to a strong economic growth. A similar pattern is observed for CO_2 emissions (Golove and Schipper, 1997). Manufacturing industry was the only sector that actually reduced total energy use and CO_2 emissions between 1970 and the early 1990s. This is mainly due to efficiency improvement, followed by a change in industrial structure towards higher production value until 1989 (Golove and Schipper, 1996) (see Fig. 1), although the contribution of the manufacturing industry to the GDP has not declined. Most recently, trends seem to suggest an increasing change in the overall structure of the US economy, contributing to a de-coupling of energy use and economic growth. While it is likely that energy prices and policies affect energy use, the analyses are unable to directly measure the effect of energy prices and energy policies on manufacturing energy use. Golove and Schipper (1996) show that during and shortly after the price shocks of the 1970s and 1980s manufacturing industry mainly reacted by adapting the structure of the sector, rather than decreasing energy intensity. Compared to pre-1970, energy intensity changes have increased but they sustained in the second half of the 1980s, when energy prices declined.

In this study, the industrial sector includes manufacturing (e.g. chemicals) and non-manufacturing sectors (e.g. mining). Fig. 2 shows the contribution of each industrial sub-sector to the total industrial primary energy use in 1997. Energy-intensive industries such as the chemical industry are still the largest energy users although the share of light industries, such as other manufacturing industries and the production of metal-based durable products, has grown over the past few years.

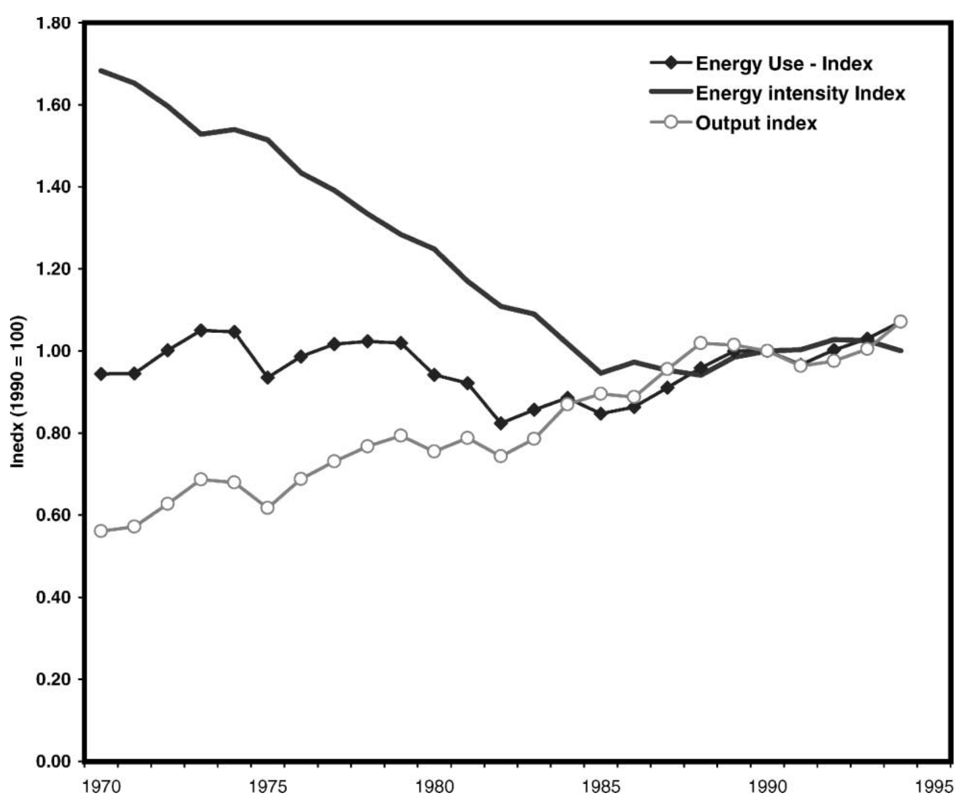

Fig. 1. Historical development of manufacturing output, energy use and energy intensity of the US manufacturing industry.

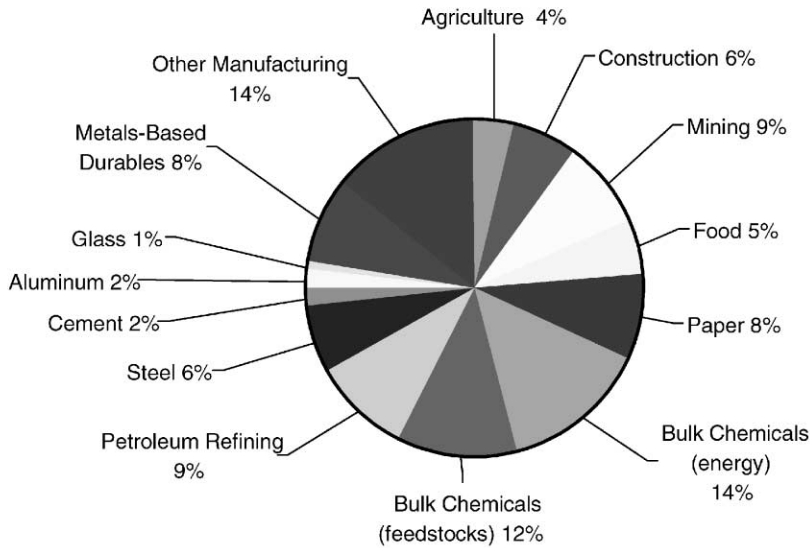

Fig. 2. Primary energy use in industry (totally 37 EJ) by industrial sub-sector in 1997.

In 1997, industrial energy use and process emissions from cement manufacture accounted for 33% of the total US CO_2 emissions, equivalent to 494 Mt C (US DOE, EIA, 1998). The largest CO_2-producing sub-sector was bulk chemicals, followed by sectors of other manufacturing and petroleum refining, respectively. The cement industry was responsible for a higher share of CO_2 emissions than the primary energy use due to the process emissions from calcination of limestone for the production of clinker. In our analysis, process CO_2 emissions from calcination are added to the cement sub-sector energy-related CO_2 emissions. Other sectors also emit process emissions, which have partially been accounted for (e.g. chemical industry) or excluded (e.g. limestone use in the steel industry) due to the lack of reliable data. The share of CO_2 emissions from the paper sector is lower than the share of energy use, due to the significant consumption of biomass. We assign zero CO_2 emissions to the combustion of biomass due to the assimilation of biomass that is grown in a sustainable way.

3. Methodology

For the analysis, we used an adapted version of the EIA's National Energy Modeling System, which is used for energy forecasting. In NEMS, energy use can be modeled at the energy service demand, or process stage, level for some energy-intensive industries, while for other sectors neither an equipment is explicitly modeled nor are there any engineering links between process stages, and technology is represented parametrically. The parameterized value is the unit energy consumption (UEC), which is the energy use per unit of production, divided by process stage. For non-manufacturing and non-energy intensive manufacturing, each fuel-specific UEC applies to the entire production process, for which the output is defined in monetary terms. For the energy-intensive sectors, UECs are given at many different process levels. UECs are specified for both new and retrofit equipment. Additionally, the UECs change over time according to a technology possibility curve (TPC). This gives the ultimate UEC that a process will reach at the end of the analysis period. The actual UEC moves along the TPC with each year of the analysis. The user can also specify the turnover rate for new and retrofit equipment, which, coupled with an improving UEC, models the penetration of more efficient technologies in the scenario.

The CEF-NEMS Industrial Module contains no explicit equipment characterizations, but the UEC and TPC parameters can be calculated based on assumptions of technology performance and penetration. These estimates are an exogenous input to the model, so there is no way to model technology choice or to capture any feedbacks from the scenario, such as price changes. We analyze two policy-driven scenarios using the CEF-NEMS model. The CEF-NEMS model does not allow direct modeling of demand side policies in the industrial sector. Hence, extensive changes were made to the model inputs to reflect the actions due to new policies in the policy scenarios, as outlined in the methodology section. The projected changes in inputs are based on analyses by industry, government and academic sources. For the CEF policy scenarios, new inputs were developed for the CEF-NEMS model, as described in the next few sections.

3.1. Business-as-usual scenario

In the CEF study we modified EIA's reference case forecast (EIA, 1998) as the business-as-usual scenario. We adopt the energy consumption data of the AEO99 reference case for the business-as-usual scenario for all industrial sub-sectors except for paper, cement, steel, and aluminum, the first three of which we analyzed in detail. For the paper, cement, and steel sectors, our estimates of physical energy intensities by process differed from those used in the AEO99. Hence, for these three sectors, we modified the NEMS baseline energy intensities (UECs) and the annual rate of improvement in the UECs over time (TPCs). We also changed the retirement rates for all sub-sectors to reflect actual lifetimes of installed equipment, based on detailed assessments of equipment ages and future developments in these sectors. Although NEMS does not treat equipment lifetime endogenously, it is possible to define the retirement rate for process equipment. Retirement rates for industrial technologies in the AEO99 scenario seem to be low, when compared to other sources (BEA, 1993; Jaccard and Willis, 1996), or assessments of technical and economic lifetimes of technologies. All the modifications to the AOE99 reference case result in a slightly lower CEF-NEMS business-as-usual energy consumption values compared to AEO99 (approximately 2% lower by 2020).

3.2. Policy scenarios

In this study we analyze two policy implementation scenarios—a Moderate scenario based on the establishment of voluntary agreements with industry that set modest annual energy efficiency improvement commitments and an Advanced scenario setting higher voluntary energy efficiency improvement commitments. The two policy scenarios assume successful implementation of a portfolio of policy measures to improve energy efficiency. Our analysis begins with an assessment of policies and programs applicable to the industrial sector. We use voluntary industrial sector agreements between industry and government as the key policy mechanism to attain energy efficiency improvements and to reduce greenhouse gas emissions. These voluntary industrial sector agreements are supported by a comprehensive package of policies and programs designed to encourage implementation of energy-efficient technologies and practices. Based on policy evaluations (ex-ante and ex-post) and different studies, we have estimated the effect of policy implementation on industrial technology choice and energy use. The effects of different policies have been combined in an effort to model the impact of the policy portfolio. The impact has been modeled by using the model inputs as discussed above. It is not possible within this paper to discuss the individual inputs, hence the reader is referred to the CEF report for details (IWG, 2000).

Each industrial sub-sector was evaluated to determine the potential energy savings and GHG emissions reductions that result from implementation of the two policy scenarios. Since voluntary industrial sector agreements include those under which a number of policies and programs contribute to decisions in order to implement energy-efficient technologies and measures, it is often difficult to allocate specific actions to specific policies or programs. Estimates are made to allocate the overall synergetic effects of actions taken due to the supporting policies and measures.

3.3. Actions addressed within CEF-NEMS

We determined where and how the energy savings might be achieved in terms of modeling parameters and modeled these changes in CEF-NEMS, on an aggregation level appropriate for the CEF-NEMS model. Some policies may affect only one modeling parameter. For example, research and development is most likely to affect the energy efficiency improvement and availability of new equipment. On the other hand, a carbon trading system will affect the price of energy and will likely influence all parameters of the model.

For *existing equipment* and *new energy-efficient technologies* in the paper, cement, and steel sectors, modifications were made based on calculations outside CEF-NEMS. For paper (Martin et al., 2000), cement (Martin et al., 1999), steel (Worrell et al., 1999), agriculture, mining, chemicals, glass, and aluminum sectors, modifications were based on recent analyses of the energy efficiency improvement potential in these sectors to determine TPCs for the Moderate and Advanced scenarios. For the remaining sectors (food, metals-based durables, and other manufacturing), we used the AEO99 HiTech Case TPC values (US DOE, EIA, 1998) for the Advanced scenario and used values between the Base Case and the HiTech Case for the Moderate scenario.

Product labeling programs and pollution prevention programs will reduce primary *resources inputs* in the paper, glass, cement, steel, and aluminum sub-sectors as these industries move toward an increased use of recycled materials. Material inputs in CEF-NEMS have been adjusted in the Moderate and Advanced scenarios to reflect such a shift. The AEO99 reference scenario shows only minor increases in recycled material inputs. For paper, the share of waste paper is increased, based on historical rates (1.7%/year (McLaren, 1997)) and technical limitations. Bleaching throughput is slightly reduced in the policy scenarios. For steel, the share of electric arc furnace production is increased in line with expectations of the industry (Barnett, 1998). For cement, we assume that 30.7 million tons of blended cement will be produced by 2010 (PCA, 1997), resulting in reduced clinker production throughout the analysis period. For aluminum, increased recycling (Plunkert, 1997) is simulated by reducing the production growth of primary aluminum production.

Expanded 'Best Practice', state programs, Clean Air programs, State Implementation Plans (SIPs), and OIT R&D programs will all contribute to the improved *boiler efficiency*. Boilers in AEO99 are modeled with a set or fixed efficiency of around 80% for those using fossil fuels and 74% for by-product boilers. In reality boiler efficiency can vary widely, e.g. between 65% and 85% for coal boilers (CIBO, 1997). Also, in NEMS, boilers are not retired, so the efficiency gains from new boilers are not captured in the model. Based on the assumptions in the BAU-scenario and assessments of boiler efficiency improvements (CIBO, 1997; Einstein et al., 1999) we have determined improvement rates for the policy scenarios, reflecting the retirement of older boilers as well as the potential impact of the policy measures.

Various programs will lead to improvements in *industrial building energy efficiency*. The NEMS model does not account for energy use in buildings in the agriculture, mining, or construction industries, but does include building energy use in all the remaining industries. For these industries, we adopt the same energy savings potential for the Moderate and Advanced scenarios as identified for commercial buildings (IWG, 2000).

3.4. Actions addressed outside CEF-NEMS

Various actions due to policies were modeled outside CEF-NEMS, although some results were fed into the CEF-NEMS model. We assessed the potential impacts of policies on retrofitting existing technologies in the paper, cement, and steel industry, and two related cross-cutting opportunities, i.e. cogeneration (or combined heat and power, CHP) and motor systems.

In the paper, cement, and steel *industrial sub-sectors* we assessed the technologies available to *retrofit* existing plants. In total, over 100 technologies were characterized with respect to potential energy savings, costs, and potential degree of implementation. The analyses focus on commercial technologies that have been implemented by plants in the US or other industrialized countries. The technologies have been ranked by cost-effectiveness in energy conservation supply curves. It is assumed that the measures are fully implemented by the year 2020, allowing a flexible response strategy. This would allow the implementation of technologies to fit the scheduled maintenance practices, reducing opportunity and transaction costs. The changes in energy intensity due to the implementation of the retrofit measures were implemented in the CEF-NEMS model as an annualized change relative to the reference year 1994. This allows credit for energy efficiency improvement achieved until today.

Combined heat and power production (CHP) is modeled separately to reflect the interaction with the power sector, effects of policy initiatives, and the replacement of retired industrial boilers (Lemar, 2001). The model allows the use of CHP for new steam generation capacity, due to the growth of steam demand in the sectors. The NEMS model does not retire old boilers. Hence, brownfield applications of CHP cannot be modeled inside the model, but are modeled exogenously. As growth in steam demand in most sectors is slow in the policy scenarios, implementation of CHP in the CEF-NEMS model itself is very limited. Hence, for CHP we relied on modeling outside the CEF-NEMS framework, to assess the impact of CHP policies.

The CHP analysis was performed using Resource Dynamics Corporation's DISPERSE model. The results were compared with results of studies using other utility models, i.e. the IPM model run for US EPA. DISPERSE estimates the achievable economic potential for CHP applications by comparing on-site generation economics with competing grid prices. The model not only determines whether on-site generation is more cost effective, but also the kind of technology and size that appears to be most economic. Fuel and electricity prices are based on those of the CEF scenarios. The overall steam demand for the industrial sub-sectors is taken from the results of the baseline and policy scenarios. Various financial parameter assumptions are taken into account, including depreciation periods, tax rates, and insurance. It was not possible to fully integrate the DISPERSE results into CEF-NEMS.[1] Hence, we were unable to assess the integrated impact on electricity generation and fuel mix. Lemar (2001) provides a more detailed description of the DISPERSE model and modeling results.

4. Barriers and policies

Industrial sector policies and programs are designed to address a number of barriers to investment in energy efficiency and greenhouse gas emissions reduction options including willingness to invest, information and transaction costs, profitability barriers, lack of skilled personnel, and other market barriers.

[1] Within the time frame of this study, it proved to be impossible to model the cogeneration results into CEF-NEMS model at the industrial sub-sector level. Future work is needed to balance the boiler representation used in DISPERSE-model with steam demand in CEF-NEMS and to integrate the DISPERSE-results in the integrated CEF-NEMS scenarios to estimate impact on power sector energy demand and fuel-mix, as well as second order effects, due to changes in fuel mix and energy demand.

4.1. Willingness to invest

The decision-making process to invest in energy efficiency improvement, like other investments, is shaped by the behavior of individuals or of various actors within a firm. Decision-making processes in a firm are a function of its rules of procedure (DeCanio, 1993), business climate, corporate culture, managers' personalities (OTA, 1993) and perception of the firm's energy efficiency (Velthuijsen, 1995). The behavior has been categorized in a study by EPRI in the United States, which determined nine "types" of managers (EPRI, 1990), depending on the industrial development type and management characteristics. In markets with strong growth and competition, efficiency with respect to energy and other inputs is necessary to survive. In contrast, stagnating markets are poor theatres for innovation and investment, and instead rely on already depreciated equipment to maintain low production costs. Energy awareness as a means to reduce production costs does not seem to be a high priority in many firms, despite a number of excellent examples in industry, worldwide (see e.g. Nelson, 1994).

4.2. Information and transaction costs

Cost-effective energy efficiency measures are often not undertaken as a result of lack of information or knowledge on the part of the consumer, lack of confidence in the information, or high transaction costs for obtaining reliable information (Reddy, 1991; OTA, 1993; Velthuijsen, 1995; Sioshansi, 1991; Levine et al., 1995; Ostertag, 1999). Information collection and processing consume time and resources, which are especially difficult for small firms. The information needs of the various actors are defined by the characteristics of the investors leading to a need for a diversified set of information sources.

4.3. Financial barriers

When energy prices do not reflect the real costs of energy, then consumers will necessarily invest less in energy efficiency unless such investments have additional benefits. Energy prices, as a component of the profitability of an investment, are also subject to large fluctuations. The uncertainty about future energy prices, especially in the short term, seems to be an important barrier (Velthuijsen, 1995). The uncertainties often lead to higher perceived risks, and therefore to more stringent investment criteria and a higher hurdle rate (Hassett and Metcalf, 1993; Sanstad et al., 1995). An important reason for high hurdle rates is capital availability. Capital rationing is often used within firms as an allocation means for investments, leading to even higher hurdle rates, especially for small projects with rates of return from 35% to 60%, much higher than the cost of capital (Ross, 1986). DeCanio (1993) has shown that firms typically establish internal hurdle rates for energy efficiency investments that are higher than the cost of capital of the firm.

4.4. Lack of skilled personnel

Especially for small and medium sized enterprises (SME), the difficulties of selecting and installing new energy-efficient equipment compared to the simplicity of buying energy may be prohibitive (Reddy, 1991). In many firms, there is often a shortage of trained technical personnel (OTA, 1993), because most personnel are busy maintaining production. In addition, the possible disruption of the production process is perceived as a barrier, leading to high *transition or opportunity costs*. Transition costs may include the costs of not fully depreciated production equipment, although the capital costs of the new technology in itself may be economically attractive.

4.5. Other market barriers

In addition to the problems identified above, other important barriers include: (1) the "invisibility" of energy efficiency measures and the difficulty of demonstrating and quantifying their impacts; (2) lack of inclusion of external costs of energy production and use in the price of energy, and (3) slow diffusion of innovative technology into markets. A full discussion of these topics is beyond our scope (see Brown, 2001; Levine et al., 1994; Fisher and Rothkopf, 1989; Hirst and Brown, 1990; Sanstad and Howarth, 1994). Many companies are risk averse with regard to a possible effect on product quality, process reliability, maintenance needs or uncertainty about the performance of a new technology (OTA, 1993). Firms are therefore less likely to invest in new, commercially unproven technology. Aversion of perceived risks seems to be a barrier especially in SMEs (Yakowitz and Hanmer, 1993).

5. Policies and programs

Voluntary sector agreements between government and industry are used as the key policy mechanism to attain energy efficiency improvements and to reduce greenhouse gas emissions because an integrated policy accounting for the characteristics of technologies, plant-specific conditions, and industrial sector business practices is needed. Policies and measures supporting these voluntary sector agreements should account for the diversity of the industrial sector while at the same time being flexible and comprehensive, offering a mix of policy instruments, giving the right incentives to the decision-maker at the firm level, and providing the flexibility needed to implement industrial energy efficiency measures. Industry is extremely diverse, and even within one sub-sector large variations in the characteristics may be found. Various instruments which support the voluntary sector agreements, both at the federal level and state level, are put in place in the policy scenarios to reach the very diverse stakeholders.

Voluntary agreements are "agreements between government and industry to facilitate voluntary actions with desirable social outcomes, which are encouraged by the government, to be undertaken by the participants, based on the participants' self-interest" (Story, 1996). A voluntary agreement can be formulated in various ways; two common methods are those based on specified energy efficiency improvement targets and those based on specific energy use or carbon emissions reduction commitments. Either an individual company or an industrial sub-sector, as represented by a party such as an industry association, can enter into such voluntary industrial agreements.

In this study, the voluntary industrial sector agreements are defined as a commitment for an industrial partner or association to achieve a specified energy efficiency improvement potential over a defined period. The level of commitment, and hence specified goal, varies with the Moderate and Advanced scenario. The number and degree of supporting measures also vary with the two scenarios, where we expect the increased industrial commitment to be met with a similar increased support effort by the federal and state government. The effectiveness of voluntary agreements is still difficult to assess due to the wide variety of voluntary agreements. Also, many are still underway as voluntary agreements typically have a long running time, making it difficult to assess the effectiveness and efficiency at this moment. Ex-post evaluations are therefore not yet available. We estimate the effect on the basis of various efforts undertaken. Voluntary industrial agreements in Japan and Germany are examples of self-commitments, without specific support measures provided by the government. Industries promised to improve energy efficiency by 0.6–1.5% per year in those countries (IEA, 1997a; Stein and Strobel, 1997). As the targets are set by sub-sector, only intra-sector structural changes are included in the targets, while inter-sector structure changes are excluded. The voluntary industrial agreements in The Netherlands have set an efficiency improvement goal of 2% per year (Nuijen, 1998; IEA, 1997b), excluding intra- and inter-sector structural change. Industries participating in the voluntary agreements in The Netherlands receive support from the government, in the form of subsidies for demonstration projects and other programs (Rietbergen et al., 1998). The voluntary agreements in The Netherlands were strongly encouraged by the government. They were also attractive to industry, as they allowed the development of a comprehensive approach, provided stability to the policy field, and were an alternative to future energy taxation (Van Ginkel and De Jong, 1995), or regulation through environmental permitting. For more details on voluntary industrial agreements, see Newman (1998), Rietbergen et al. (1998), Nuijen (1998), and Mazurek and Lehman (1999).

Evaluation of voluntary industrial sector agreements in The Netherlands showed that the agreements helped industries to focus attention on energy efficiency and find low-cost options within commonly used investment criteria (Korevaar et al., 1997; Rietbergen et al., 1998). Although the agreements themselves proved to be successful and cost-effective (Rietbergen et al., 1998), various support measures were implemented within the system of voluntary agreements. It is difficult to attribute the energy savings to a specific policy instrument; rather, it is the result of a comprehensive effort to increase implementation and development of energy-efficient practices and technologies in industry by removing or reducing barriers. This emphasizes the importance of offering a package instead of a set of individual measures.

Experience with industrial sector voluntary agreements exists in the US for the abatement of CFC and non-CO_2 GHG emissions. For example, 11 of 12 primary aluminum smelting industries in the US have signed the voluntary aluminum industrial partnership (VAIP) with EPA to reduce perfluorocarbon (PFC) emissions from the electrolysis process by almost 40% by the year 2000 (US EPA, 1999). Similar programs exist with the chemical, magnesium and semi-conductor industries, as well as voluntary methane emission abatement programs with the coal, oil and natural gas industry. New voluntary efforts include landfill operators and agriculture.

Table 1 outlines the various policies and programs that fall under the scope of voluntary industrial sector agreements in this analysis. These include expansion of a number of existing programs as well as establishment of new programs. The effects of increased program efforts are difficult to assess. Cost-effectiveness may improve due to the increased volume, but may also be less effective as programs reach smaller energy users or lead to implementation of less-effective measures. The interaction of various measures deployed simultaneously is difficult to estimate ex-ante, or even ex-post (Blok, 1993; Stein and Strobel, 1997). It is often more difficult to assess the impacts of individual programs than the estimated impact of a set of policies. For this study, we group individual programs into four categories: information dissemination; investment enabling; regulations; and research, development and demonstration. Table 2 provides an overview of the effectiveness of the selected

Table 1
Policies and programs for reducing energy use and greenhouse gas emissions from the industrial sector under the Moderate and Advanced scenarios

Policy/program	Moderate scenario	Advanced scenario
Voluntary industrial sector agreements		
Voluntary industrial sector agreements	Voluntary programs to reduce GHG emissions (CO_2 and non-CO_2) in energy-intensive and GHG-intensive industries for specific industrial process or buildings	Voluntary programs to reduce GHG emissions (CO_2 and non-CO_2) in all industries, including benchmarking
Voluntary programs		
Expanded challenge programs		
Motor and compressed air challenge	Increased effort to assist in overall motor system optimization through increased education, technical assistance, training, and tools. Increased promotion of use of adjustable-speed drives	Increased promotion of overall motor system efficiency and use of adjustable-speed drives by offering greater financial incentives
Steam challenge	Outreach, training, and development of assessment tools are increased	Expanded to include outreach to smaller boiler users and to develop automated monitoring and controls
CHP challenge	Financial incentives, utility programs promoting CHP, and expanded removal of barriers (e.g. permitting) are added	Program expands to include increased outreach, dissemination, and clearing-house activities
Expanded ENERGY STAR buildings and green lights	Development of best practices management tools and benchmarking information. Floorspace covered by program increases by 50%	Best practices management tools and benchmarking information expanded and more extensively marketed. Floorspace covered by program increases by 100%
Expanded ENERGY STAR and climatewise program	Increased efforts in the currently addressed sectors and program expansion to include glass, steel, and aluminum as well as selected light industries	Program expanded to include light industries, agriculture, construction, and mining
Expanded pollution prevention programs	Expanded effort leads to increased recycling in the steel, aluminum, paper, and glass industries	Number of partners expected to grow to 1600 by 2020 (from 700 in 1997)
Information programs		
Expanded assessment programs	Number of industrial assessment centers increases from 30 to 35 and number of assessments per center increases from 30 to 36 per year. Expanded to include business schools and community colleges. Added emphasis on increased follow-up	Number of industrial assessment centers increases to 50 and number of assessments per center increases to 40 per year. Comprehensive energy plans for each audited facility added
Product labeling and procurement	Development of labels for two products	Labeling expanded to other products (e.g. glass bottles). Marketing of labels is increased and government procurement policies are revised to include labeled products
Investment enabling programs		
Expanded state programs		
State industrial energy efficiency programs	Current state level programs are expanded to include information dissemination, audits, demonstration programs, and R&D. Participation grows from less than half of the states to 30 states	Programs expanded to include all 50 states

Clean air partnership fund	Expanded use of integrated approaches for complying with CAA. Expanded demonstration of new technologies	GHG emissions reduction projects given higher priority
Expanded ESCO/utility programs		
Standard performance contracting (line charge)	Expansion of line charges to 30 states and increased efforts to target small industrial customers	Expansion of line charges to 50 states and further increased efforts to target small industrial customers
Financial incentives		
Tax incentives for energy managers	Expected to provide tax rebates of 50% of the salary of an energy manager to 5000 medium and large energy-using industries by 2020	Tax rebates expected to be provided to 10,000 medium and large energy using-industries by 2020
Tax rebates for specific industrial technologies	Increased rebates focus on implementation of advanced technologies	Increased rebates focus on implementation of advanced technologies. Increased funding leads to accelerated adoption of these technologies
Investment tax credit for CHP systems	Tax credit extended from 2003 to 2020, leading to an expansion of CHP as well as third party producers at industrial sites	Tax credit expected to be extended from 2003 to 2020, leading to an expansion of CHP as well as third party producers at industrial sites
Regulations		
Motor standards and certification	Mandates upgrade of all motors to EPACT standards by 2020. Extends standards to all motor systems and enforces 100% compliance. Promotes national motor repair standard	Extends standards to all motor systems and enforces 100% compliance. Mandates national motor repair standard
State implementation plans/clean air partnership fund	Identifies control measures and regulations to adopt and enforce the control strategies	Identifies control measures and regulations to adopt and enforce the control strategies
Research & development programs		
Expanded demonstration programs	Demonstration programs expanded in currently addressed sectors and extended to mining and construction sectors. Number of demonstration programs increased from 10 to 15 per year	Extent of demonstration programs further expanded in all sectors and incorporated into state demonstration programs. Number of demonstration programs increases to 18 per year
Expanded R&D programs		
Industries of the future	Increased R&D efforts in all the industries currently in program	Increased R&D efforts in all industries currently in program and expansion of a number of smaller "other manufacturing" industries
Other OIT R&D programs	Program R&D efforts increased in all areas related to improving industrial sector energy efficiency	Industrial sector energy efficiency R&D efforts further increased
Domestic CO_2 emissions trading system	N/A	

Table 2
Policies to address barriers to efficiency improvement in the industrial sector

	Policies											
	Voluntary agreements	Expanded demonstration programs	Expanded assessment programs	Expanded challenge programs	Expanded labeling programs	Expanded state programs	Expanded R&D Programs	Expanded ESCO/utility Programs	Expanded Climatewise program	Expanded pollution prevention	Financial incentives	Carbon trading system
Scenario	Both	Both	Both	Both	Both	Both	Both	Both	Both	Both	Both	Advanced
Barriers												
Willingness to invest	X	X	X	X				X		X	X	
Information/transaction costs	X	X	X	X	X	X		X	X	X		
Profitability		X		X			X	X			X	X
Lack of skilled personnel			X	X		X		X				
Pricing				X							X	X
Innovation		X		X		X	X			X		
Renter/landlord								X				

policies and programs to address the barriers to energy efficiency improvement.

6. Scenario results

This study identified policies to improve industrial energy efficiency through increased implementation of efficient practices and technologies. A number of cross-cutting technologies can achieve significant improvements in all industries. These include preventative maintenance, pollution prevention and waste recycling (e.g. steel, aluminum, cement, and paper), process control and management, steam distribution system upgrades, improved energy recovery, cogeneration (CHP), and drive system improvements. However, a large share of the efficiency improvements is achieved by retiring old process equipment and replacing it with the state-of-the-art equipment. This is especially true for many capital-intensive industries (Steinmeyer, 1997). This emphasizes the need for flexibility in achieving energy efficiency improvement targets, as provided by the voluntary industrial agreements.

Energy savings are found in *all industrial sub-sectors*. Production growth is lower in the most energy-intensive industries than the less energy-intensive manufacturing industries. This leads to a relative reduction in energy use and CO_2 emissions by the energy-intensive industries. Hence, most of the growth in energy use and emissions can be found in the light industries, that are expected to grow to approximately 49% of the primary energy consumption in the BAU scenario by 2020. At first, energy efficiency improvements in the policy scenarios appear to be high; however, the efficiency improvements in the light industries in the baseline scenario are almost zero. While light industries would consume almost half of the energy by 2020 in the BAU scenario, almost 50% of the total energy savings in the Advanced scenario are also found in these industries.

The characteristics of decision-makers vary widely, as is evidenced by the literature on policies. Hence, there is no "deus ex machina" or "silver bullet" policy; instead, an integrated policy accounting for the characteristics of technologies and target groups is needed. Acknowledging the differences between individual industries (even within one economic sector) is essential to develop an integrated policy accounting for the characteristics of technologies, conditions and target groups. Policies and measures supporting these voluntary industrial agreements should account for the diversity of the industrial sector while at the same time being comprehensive and flexible, offering a mix of policy instruments, giving the right incentives to the decision-maker at the firm level, and providing the flexibility needed to implement industrial energy efficiency measures.

In this study, we have evaluated a large number of policy measures, based on current and potential future initiatives. The voluntary industrial agreements are assumed to integrate the various individual policy measures and provide access to the resources and policies. The framework will strengthen the effects and effectiveness of the individual policy instruments. Hence, it is difficult to highlight individual key policies.

6.1. Business-as-usual scenario

In the business-as-usual (BAU) scenario, industrial energy use is expected to grow from 36.7 PJ in 1997 to 43.3 EJ in 2020, which is almost equal to that of the AEO99 (44.4 EJ) (see Fig. 3). The difference between AEO99 and the CEF BAU scenario is due to changes in retirement rates, and changes in the energy consumption of the three sectors modeled in detail, i.e. cement, iron and steel, and pulp and paper. Energy use in the BAU scenario shows a slight growth of 0.7%/year, while industrial output grows by almost 1.9%/year. Hence, the aggregate industrial energy intensity decreases by about 1.1%/year, or 23% over the scenario period. The intensity change in the AEO99 scenario is largely due to inter-sector structural change (almost three-fourths of the change), i.e. a shift to less energy-intensive industries, and energy efficiency improvement (about one-fourth). Carbon dioxide emissions from the industrial sector in the BAU scenario increase by nearly 0.7%/year to 578 Mt C.

The growth in energy use in the BAU scenario is mainly found in other manufacturing industries (e.g. metals-based durables, and other manufacturing sectors) and the non-manufacturing industries. Growth in energy use is due to the high economic growth of these sectors, and the slow improvement of energy efficiency. Food and bulk chemical industries also contribute to the growth. Energy use in the energy intensive industries grows slightly, or is even reduced, due to slower economic growth in these sectors, resulting in the inter-sector structural change of the economy. By 2020, energy-intensive industries will still consume 51% of the total industrial energy use, down from 55% in 1997 (primary energy, including feedstocks).

The industrial fuel-mix changes slightly towards less carbon-intensive fuels (more natural gas, less coal). The iron and steel industry is the largest coal consumer. Relative low production growth, associated with reductions in coke use result in a downward trend of coal use, and a reduction in the imports of coke. The importance of biomass in the industrial fuel-mix increases from 5% to 6%, mainly due to improved utilization in the pulp and paper industry. Purchased electricity is expected to increase its share of the site fuel-mix, from 13% in 1997 to 14% in 2020.

6.2. Moderate scenario

In the Moderate scenario, industrial energy use is expected to grow from 36.7 EJ in 1997 to 40.0 EJ in 2020, equivalent to a growth of 0.4%/year (excluding CHP). Total industrial energy use in 2020 under the Moderate scenario is about 8% lower than the BAU scenario. Under the conditions in the Moderate scenario, the overall industry energy intensity falls by 1.5%/year. Intra-sector, inter-sector and energy efficiency improvement contribute to the observed changes. The policies in the Moderate scenario are assumed to be effective by 2000, and are increased in the period after 2000. This reflects a relatively strong growth in industrial energy use in the first few years of the scenario period, followed by a reduction later in the

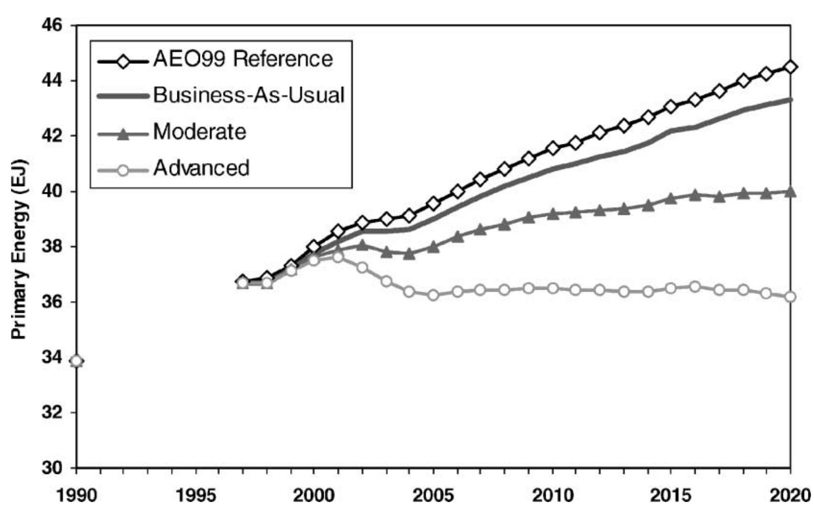

Fig. 3. Scenario results for the primary industrial energy use in the US industry for the period 1997–2020. The results exclude the additional energy savings from accelerated implementation of CHP.

same. Annual carbon emissions are increasing to approximately 521 Mt C, or reducing by 10% relative to the BAU scenario. The changes in carbon intensity are a bit larger due to the shift towards lower carbon fuels, as well as intra-sectoral structure changes in the cement, paper and steel industries.

Under the policies in the Moderate scenario, the light non-energy intensive industries will remain the largest contributors to future growth in energy demand, and carbon dioxide emissions. The high growth in the BAU scenario is offset by considerable efficiency improvements (approximately 0.4%/year) in those industries under the Moderate scenario. A small change in the fuel-mix will result in a larger reduction in carbon dioxide emissions in the light industries. The overall acceleration of energy efficiency improvement rates in these two sectors in the Moderate scenario is relatively modest at 0.3%/year. The other energy-intensive industries show a relatively strong improvement rate over the BAU scenario, mostly due to increased energy efficiency improvement. This will result in a 6% reduction in total energy use by 2020.

The overall fuel-mix in industry is changing more rapidly to low carbon fuels, when compared to the BAU scenario. Coal and petroleum products show the strongest decrease, at double the rate of that of natural gas. While coal use stabilizes in the steel industry, reductions in coal use are mostly found in the non-energy intensive industries. By 2020, natural gas will provide almost a third of the primary energy needs of the total industry. This change in fuel-mix will result in lower carbon dioxide emissions.

Energy service costs, which include annual fuel costs, annualized incremental technology cost of energy efficiency improvement, and annual program costs to promote energy efficiency, will decrease by approximately 9% by 2010 and 10% by 2020, relative to the BAU scenario (see Table 6).

6.3. Advanced scenario

In the Advanced scenario, a stronger push to reduce GHG emissions will result in an active policy for energy efficiency improvement and GHG emission reduction. This is expected to result in considerable energy savings and carbon dioxide emissions. In the Advanced scenario, industrial energy use remains stable, decreasing from 36.7 EJ in 1997 to approximately 36.1 quads in 2020 (excluding CHP). The total industrial energy use in 2020 under the Advanced scenario is expected to be 16.5% lower than the BAU scenario. Under the conditions in the Advanced scenario, the overall industry energy intensity falls by 1.8% per year (see Fig. 4), of which 1.0% per year is due to energy efficiency improvement.

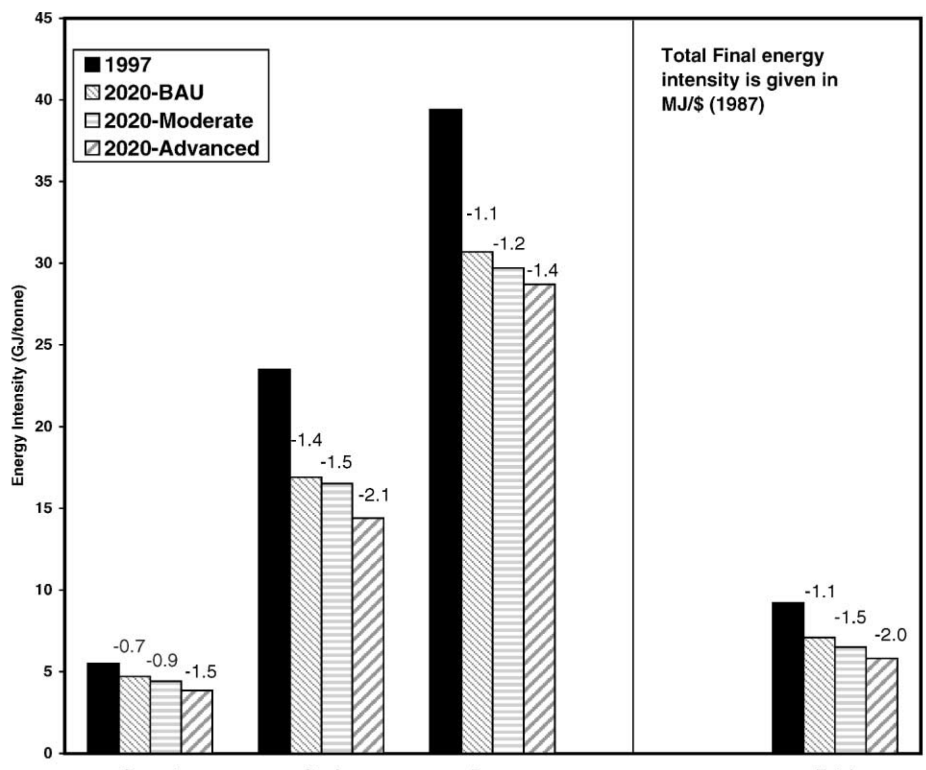

Fig. 4. Energy intensity changes in the three scenarios for total industry and for cement, iron and steel and pulp and paper industries for 2020. The 1997 energy intensities are given for comparison.

This compares well with the experiences in Germany, Japan and The Netherlands, that voluntary industrial agreements can potentially contribute an efficiency improvement of 0.4% to 1.3% per year. Intra-sector, inter-sector and energy efficiency improvement contribute to the total observed changes. Carbon emissions are actually decreasing to approximately 409 Mt C, or reducing by 29% relative to the BAU scenario, especially due to de-carbonization in the power sector.

Energy efficiency improvement rate in the non-energy-intensive industries is about 0.9% per year, which reflects the total efficiency improvement. This is due to changes in process efficiency, as well as in energy use in industrial buildings. The change in the cement industry is mainly due to the more aggressive introduction of blended cements in the US market, resulting in energy savings as well as process CO_2 emission reduction in the clinker-making. Similarly, increased use of electric steel-making will result in energy savings in the steel industry. Introduction of new plants contributes a large part of the total energy savings in other industries.

In the Advanced scenario, the fuel-mix is expected to favor low carbon fuels due to the emission trading system. This will lead to a 30% reduction in the share of coal, and 19% reduction in the share of oil, relative to the BAU scenario. Large reductions in the carbon dioxide emissions are due to the lower carbon emissions in the power sector, especially in the electricity intensive sectors, e.g. aluminum and the non-energy intensive industries. This leads to a strong reduction in the total carbon dioxide emissions. While increased CHP in industry is expected to impact the observed shift to natural gas, the CHP results have not been completely integrated in the current fuel-mix shift.

The annual energy service costs in the Advanced scenario will be reduced by 8% in 2010 and by 12% by 2020, translating to cost savings of approximately \$8 and \$14 billion, respectively (see Tables 3–6). The savings are expected to be significantly higher in 2020 than in 2010, due to the larger investments in energy R&D in the Advanced scenario, which will result in greater energy savings in the long term.

6.4. Cogeneration

In this section we only summarize the results, while Lemar (2001) provides a more detailed overview of the CHP analysis. The results exclude district heating and distributed generation outside industry. The market penetration of industrial CHP in the two CEF policy scenarios is estimated to be between 40 and 76 GW by 2020, and depends on the timing and impact of CHP policies designed to remove technical and market barriers. In the BAU scenario, 8.8 GW of new CHP is projected, based on a continuation of current market penetration trends. Several technical and market barriers stand in the way of further use of CHP, as evidenced by the fact that over 80 percent of the potential capacity is projected as untapped. Most potential for CHP can be found in the paper, chemical, food and the non-energy-intensive manufacturing sub-sectors.

In the Moderate scenario, the projected additional CHP-capacity is expected to grow to approximately 14 GW by 2010 and 40 GW by 2020. This includes 3 GW of integrated black liquor gasification cogeneration by 2020. In the Moderate scenario, the net impact in 2020 is the energy savings of 0.53 EJ and a reduction in carbon dioxide emissions of 9.7 Mt C (Lemar, 2001).

In the Advanced scenario, the projected level of new CHP is expected to reach approximately 29 GW by 2010 and 76 GW by 2020. More aggressive policies designed to remove financial barriers, expedite siting and permitting, improve grid sell back pricing, and reduce interconnection and backup power costs, all contribute to the improved market penetration levels as well as reduce the costs of the ATS. This leads to an accelerated implementation of CHP, despite the lower steam demand due to energy efficiency improvement. In the Advanced scenario, newly installed CHP is expected to lead to a net energy savings of 2.5 EJ in 2020 and a reduction in carbon dioxide emissions of 39.7 Mt C (Lemar, 2001).

7. Future analysis needs

Currently, most available energy models are not capable of explicitly modeling policies. Generally, models represent the actions following policy implementation. Decision-makers react differently to the implemented policies and measures, depending on their (perceived) situation. This will affect the effects and effectiveness of policies. Research in many countries is ongoing to assess and “model” decision-making behavior. This has not yet resulted in commonly acceptable methodologies. To model the relationship between actions and policies requires substantial multi-disciplinary research.

7.1. Modeling

In modeling the scenarios, we found various issues that warrant further research and adaptation of the model. Like most energy models, the NEMS framework distinguishes industrial sub-sectors to model technical changes in energy efficiency. The different sub-sectors may not accurately reflect the characteristics for decision-making processes in different companies. This limits the modeling within NEMS to modeling the expected actions (in the form of technical changes) that follow implementation of policies. Development of

Table 3
Primary energy use by scenario, sub-sector, and fuel in the industrial sector (expressed in Exajoules, EJ), excluding the effects of increased CHP[a]

Sector & fuel	1990	1997	2010					2020				
			BAU	Moderate		Advanced		BAU	Moderate		Advanced	
	EJ	EJ	EJ	EJ	%	EJ	%	EJ	EJ	%	EJ	%
Iron and steel												
Petroleum		0.13	0.12	0.13	2.3	0.04	−68.6	0.11	0.11	−0.7	0.02	−80.3
Natural gas		0.57	0.47	0.42	−9.8	0.40	−15.6	0.41	0.36	−14.1	0.36	−14.2
Coal		0.92	0.84	0.85	1.1	0.80	−4.4	0.82	0.83	0.6	0.80	−3.1
Primary electricity		0.59	0.56	0.53	−5.0	0.46	−16.8	0.53	0.47	−10.2	0.42	−21.4
Total primary		2.20	1.98	1.93	−3.1	1.70	−14.4	1.88	1.77	−5.8	1.59	−15.1
Paper												
Petroleum		0.13	0.12	0.11	−7.7	0.08	−31.4	0.11	0.08	−13.2	0.07	−29.1
Natural gas		0.71	0.53	0.55	3.8	0.38	−27.4	0.45	0.54	18.8	0.45	0.3
Coal		0.41	0.33	0.30	−10.0	0.13	−60.8	0.28	0.24	−14.9	0.12	−60.3
Renewables		1.56	1.91	1.88	−1.5	2.05	7.1	2.11	2.03	−3.7	2.31	9.5
Primary electricity		0.88	0.84	0.82	−3.5	0.70	−17.6	0.83	0.77	−6.9	0.60	−27.8
Total primary		3.69	3.73	3.65	−2.2	3.33	−10.6	3.78	3.67	−2.8	3.54	−6.1
Cement												
Petroleum		0.04	0.04	0.03	−3.9	0.04	7.8	0.03	0.03	−7.2	0.03	3.0
Natural gas		0.02	0.02	0.02	16.3	0.03	105.9	0.01	0.02	24.3	0.03	119.1
Coal		0.34	0.34	0.32	−3.9	0.25	−22.9	0.33	0.31	−8.0	0.23	−30.9
Renewables		0.00	0.00	0.00	N/A	0.00	N/A	0.00	0.00	N/A	0.00	N/A
Primary electricity		0.11	0.10	0.10	−1.0	0.10	−2.5	0.10	0.10	−2.9	0.08	−11.6
Total primary		0.50	0.49	0.47	−2.7	0.42	−12.1	0.47	0.44	−5.9	0.38	−20.0
Other energy-intensive												
Petroleum		5.4	6.1	5.8	−5.1	5.5	−9.9	6.2	5.6	−11.3	5.0	−20.5
Natural gas		5.0	5.4	5.4	0.0	5.2	−4.8	5.9	5.9	0.6	5.6	−5.2
coal		0.2	0.2	0.2	−19.1	0.1	−49.5	0.2	0.1	−36.1	0.1	−64.7
Renewables		0.0	0.0	0.0	N/A	0.0	N/A	0.0	0.0	N/A	0.0	N/A
Primary electricity		3.3	3.4	3.2	−5.7	2.7	−19.4	3.4	3.0	−12.9	2.3	−33.2
Total primary		13.8	15.1	14.6	−3.6	13.5	−10.7	15.8	14.6	−7.6	12.9	−18.2
Non-energy-intensive												
Petroleum		3.2	4.0	3.8	−5.8	3.7	−7.9	4.4	4.0	−10.3	3.8	−14.8
Natural gas		5.1	6.1	5.7	−6.3	5.5	−9.6	6.8	6.0	−11.7	5.6	−17.3
coal		0.6	0.7	0.7	−6.8	0.5	−26.7	0.8	0.7	−11.5	0.5	−35.9
Renewables		0.4	0.5	0.5	0.6	0.5	0.4	0.6	0.6	1.3	0.6	0.5
Primary electricity		7.1	8.0	7.8	−3.1	7.3	−9.8	8.7	8.3	−5.1	7.2	−17.4
Total primary		16.5	19.4	18.6	−4.7	17.5	−9.8	21.3	19.5	−8.4	17.6	−17.1
Total industrial												
Petroleum		8.9	10.3	9.8	−5.3	9.4	−10.0	11.0	9.7	−10.8	8.9	−18.8
Natural gas		11.3	12.6	12.1	−3.3	11.5	−8.4	13.5	12.8	−5.4	12.0	−11.2
Coal		2.5	2.5	2.3	−5.2	1.9	−25.1	2.5	2.2	−9.8	1.8	−30.0
Renewables		2.0	2.4	2.4	−1.1	2.5	5.6	2.7	2.6	−2.6	3.0	7.5
Primary electricity		11.9	12.9	12.4	−3.8	11.2	−13.1	13.6	12.6	−7.4	10.6	−22.1
Total primary	33.9	36.6	40.7	39.1	−4.0	36.4	−10.5	43.3	40.0	−7.4	36.1	−16.5

[a] (1)BAU = business-as-usual scenario, and (2) % (change) is relative to the BAU scenario in that year.

models that are able to assess the impact of policies is strongly encouraged.

Retirement rates for industrial technologies in the NEMS model seem to be low, when compared to assessments of technical and economic lifetimes of technologies. Retirement rates are important in assessing future industrial energy use because new technologies often have significantly different energy use characteristics. The importance would warrant future analysis of actual age distribution of the main energy consuming processes in the sub-sectors.

Energy use in industries is broken down (where appropriate) into process, buildings and boilers and power generation. In the current NEMS model, boiler efficiency has been set at a standard efficiency rate, and hence does not improve over time, nor are boilers

Table 4
Carbon emissions by scenario, sub-sector, and fuel in the industrial sector (expressed in Mt C), excluding the effects of increased CHP[a]

Sector & fuel	1990	1997	2010					2020				
			BAU	Moderate		Advanced		BAU	Moderate		Advanced	
	Mt C	Mt C	Mt C	Mt C	%	Mt C	%	Mt C	Mt C	%	Mt C	%
Iron and steel												
Petroleum		1.93	1.72	1.76	2.2	0.53	−69.3	1.52	1.49	−1.8	0.29	−81.1
Natural gas		7.40	6.08	5.48	−9.8	5.12	−15.8	5.33	4.58	−14.0	4.57	−14.1
Coal		21.61	20.25	20.46	1.1	19.37	−4.4	19.83	19.95	0.6	19.24	−3.0
Electricity		8.63	8.72	7.94	−8.9	5.78	−33.7	8.53	7.31	−14.3	4.62	−45.8
Total		39.56	36.76	35.64	−3.0	30.79	−16.2	35.21	33.33	−5.3	28.72	−18.4
Paper												
Petroleum		1.99	1.65	1.52	−7.8	1.11	−32.9	1.43	1.22	−14.2	0.97	−32.1
Natural gas		9.19	6.84	7.09	3.7	4.95	−27.6	5.83	6.93	18.9	5.84	0.3
Coal		9.75	7.95	7.16	−10.0	3.12	−60.8	6.82	5.80	−14.9	2.71	−60.3
Renewables		0.00	0.00	0.00	N/A	0.00	N/A	0.00	0.00	N/A	0.00	N/A
Electricity		12.87	13.35	12.35	−7.5	8.76	−34.4	13.34	11.86	−11.1	6.63	−50.3
Total		33.80	29.79	28.12	−5.6	17.93	−39.8	27.41	25.81	−5.8	16.15	−41.1
Cement												
Petroleum		0.59	0.54	0.52	−4.0	0.57	5.3	0.49	0.45	−8.3	0.49	−1.3
Natural gas		0.25	0.21	0.24	16.3	0.43	105.5	0.19	0.23	24.4	0.41	119.1
Coal		7.80	8.02	7.70	−4.0	6.19	−22.7	7.92	7.29	−8.0	5.49	−30.8
Renewables		0.00	0.00	0.00	N/A	0.00	N/A	0.00	0.00	N/A	0.00	N/A
Electricity		1.49	1.52	1.44	−5.1	1.18	−22.7	1.49	1.38	−7.3	0.91	−39.1
Total energy emissions		10.13	10.28	9.90	−3.7	8.37	−18.7	10.10	9.36	−7.3	7.29	−27.8
Process emissions		10.98	11.83	11.32	−4.3	11.32	−4.3	12.20	11.60	−4.9	10.56	−13.4
Total		21.11	22.11	21.22	−4.0	19.69	−11.0	22.30	20.96	−6.0	17.85	−20.0
Other energy-intensive												
Petroleum		50.8	53.7	50.7	−5.7	45.9	−14.6	51.5	44.2	−14.3	36.2	−29.8
Natural gas		59.6	65.2	65.3	0.2	61.9	−5.0	70.8	71.7	1.3	67.4	−4.7
Coal		4.4	5.0	4.0	−19.1	2.5	−49.4	5.7	3.7	−36.1	2.0	−64.7
Renewables		0.0	0.0	0.0	N/A	0.0	N/A	0.0	0.0	N/A	0.0	N/A
Electricity		47.9	52.7	47.7	−9.5	33.8	−35.8	54.5	45.4	−16.8	25.1	−54.0
Total		162.6	176.6	167.7	−5.0	144.2	−18.4	182.6	164.9	−9.7	130.7	−28.4
Non-energy-intensive												
Petroleum		50.5	58.2	54.7	−5.9	52.3	−10.1	63.1	55.9	−11.5	51.4	−18.6
Natural gas		65.8	79.0	74.0	−6.4	71.2	−9.9	87.4	77.2	−11.6	72.2	−17.3
Coal		14.9	18.4	17.1	6.8	13.5	−26.6	20.0	17.7	−11.5	12.8	−35.8
Renewables		0.0	0.0	0.0	N/A	0.0	N/A	0.0	0.0	N/A	0.0	N/A
Electricity		104.7	126.7	117.8	−7.0	90.9	−28.2	139.5	126.4	−9.4	79.4	−43.1
Total		236.0	282.3	263.6	−6.6	228.0	−19.2	310.0	277.2	−10.6	215.8	−30.4
Total industrial												
Petroleum		105.8	115.8	109.2	−5.7	100.4	−13.3	118.1	103.2	−12.6	89.3	−24.4
Natural gas		142.2	157.3	152.1	−3.3	143.6	−8.7	169.5	160.7	−5.2	150.5	−11.2
Coal		58.5	59.6	56.5	−5.2	44.7	−25.0	60.3	54.4	−9.8	42.3	−29.9
Renewables		0.0	0.0	0.0	N/A	0.0	N/A	0.0	0.0	N/A	0.0	N/A
Electricity		175.6	203.0	187.2	−7.8	140.5	−30.8	217.4	192.3	−11.5	116.6	−46.4
Total energy emissions		482.1	535.7	505.0	−5.7	429.2	−19.9	565.3	510.6	−9.7	398.7	−29.5
Total process emissions		11.0	11.8	11.3	−4.3	11.3	−4.3	12.2	11.6	−4.9	10.6	−13.4
Total	452	493.1	547.5	516.3	−5.7	440.5	−19.5	577.5	522.2	−9.8	409.3	−29.1

[a] (1) BAU = business-as-usual scenario; Mt C = million metric tons of carbon, and (2) % (change) is relative to the BAU scenario in that year.

retired. We simulated retirement of boilers by a slow improvement rate of the boiler efficiency.

Energy intensity declines over the time in most industries, due to autonomous trends as well as policy effects. For some industrial sub-sectors (i.e. agriculture, mining, construction, metal-based durables and non-intensive manufacturing) NEMS assumes no autonomous improvement trend in the baseline scenario. This is contrary to long term trends observed in most industries.

Table 5
Energy intensity development in CEF-NEMS scenarios, expressed as primary energy use per unit of output[a]

Sector		Business-as-usual		Moderate		Advanced	
	1997	2010	2020	2010	2020	2010	2020
Economic intensities (MJ/\$-output (1987-\$) on a primary energy basis							
Refining	24.9	28.2	26.7	27.6	25.0	25.4	20.4
Food	4.5	4.1	3.9	4.0	3.8	3.7	3.5
Pulp & paper	29.5	25.0	23.3	24.4	22.6	22.3	21.8
Bulk chemicals	34.0	30.5	29.1	29.0	26.7	25.8	23.3
Glass	13.8	12.1	11.2	12.1	11.1	10.4	9.5
Cement	103.1	94.3	89.2	91.9	83.9	82.9	71.3
Iron & steel	31.8	25.3	23.1	24.6	21.7	21.7	19.6
Aluminum	24.6	20.3	18.3	19.5	17.5	17.1	15.5
Agriculture	5.5	5.3	5.2	5.1	4.7	4.9	4.2
Construction	5.4	5.2	5.0	4.9	4.5	4.7	4.3
Mining	22.6	23.3	23.6	21.9	21.3	21.4	20.3
Metal durables	2.1	1.9	1.7	1.8	1.6	1.6	1.4
Other manufacturing	5.8	5.4	5.1	5.2	4.6	4.9	4.1
Total	9.2	7.8	7.1	7.5	6.5	7.0	5.9
Physical intensities (GJ/tonne) on a primary energy basis							
Pulp & paper	39.4	33.0	30.7	32.3	29.8	29.5	28.7
Glass	20.0	17.7	16.4	17.7	16.3	15.2	14.1
Cement	5.5	5.4	4.7	4.8	4.4	4.3	3.7
Iron & steel	23.5	21.2	16.9	18.0	16.6	15.9	14.3
Aluminum	145.7	123.0	108.3	115.3	101.7	101.1	91.9

[a] Note: Bulk chemicals exclude feedstocks. The increased contribution of CHP is excluded in this analysis.

Table 6
Annual total costs of energy services by scenario in the industrial sector (10^9 1997\$/year)[a]

	1997	2010					2020				
		BAU	Moderate		Advanced		BAU	Moderate		Advanced	
	B\$/y	B\$/y	B\$/yr	%	B\$/yr	%	B\$/yr	B\$/yr	%	B\$/yr	%
Total-industry											
Annual fuel cost	105	109	96	−12	93	−15	115	95	−17	87	−24
Annualized incremental technology cost of energy efficiency	0	0	2.7	N/A	5.8	N/A	0	6.0	N/A	10.4	N/A
Annual program costs to promote energy efficiency	0	0	1.0	N/A	2.2	N/A	0	2.1	N/A	3.9	N/A
Annual total cost of energy services	105	109	100	−9	101	−8	115	104	−10	101	−12

[a] Note: (1) BAU = business-as-usual scenario. (2) Buildings in the industrial sector are not included in these results. (3) % (change) is relative to the BAU scenario in that year. (4) Energy service costs include cost of purchased fuels and electricity (minus any carbon permit trading fee transfer payments), and the annualized costs of incremental efficiency improvements. (5) The results exclude the increased role of industrial CHP.

7.2. Policies

Detailed evaluations of industrial energy efficiency policies are rare (Convery, 1998; Martin et al., 1998; US DOE, 1996). Estimating the effects of energy efficiency policies on energy use and economic performance is a difficult task. Our results should be seen as a first estimate. Future analysis of the effects and effectiveness of industrial energy policies is needed.

Policies are never implemented in isolation. Individual policies may have feedback effects, which could either improve or reduce the effectiveness of other policies. Little is known regarding these effects.

New technologies often improve energy and resource efficiency while reducing manufacturing costs considerably (Pye, 1998). Thin slab casting is an excellent example of a technology reducing production costs of steel products, as well as reducing energy use, considerably (Worrell et al., 1999). The productivity gains are often difficult to quantify. In our detailed technology analysis of the three subsectors, we incorporated these costs in the assessments of the energy efficiency improvement potentials. However, future research is needed to quantify the other benefits of energy efficiency measures better.

Economic development follows cycles. However, most energy modeling tools (including NEMS) use continuous growth trends. The effects and effectiveness of policies will depend on the phase of the business cycle, especially when modeling short-term effects. The 20-year time period in this analysis may be less sensitive to these effects.

The results of the scenario analysis have shown that strong economic growth in the light manufacturing industries may considerably affect future emissions in the industrial sectors. However, knowledge on energy efficiency and GHG emission reduction options in these sectors is very scattered. Assessment of energy efficiency opportunities in these sectors is needed.

Climate change abatement policies will not be limited to policies and measures with respect to CO_2 emissions. Industry also emits varying quantities of five other GHGs, distinguished in the Kyoto Protocol. An industrial GHG abatement strategy and policy will also include the other five GHGs. It is argued that this may lead to a more cost-effective strategy (Reilly et al., 1999). This study has only addressed the CO_2 emissions related to energy use and process emissions from clinker manufacture in the cement industry. Future work should address the contribution of abatement of other gases and the cost-effectiveness of such actions and policies.

8. Conclusions and summary

The study demonstrates that there are substantial potentials for further efficiency improvement in industry. This is accomplished by investigating three policy scenarios, which entail different degrees of commitment to improve energy efficiency to address the energy, economic and environmental challenges faced by the US industry. The scenarios reflect alternative views of the urgency with which policy-makers and the American people will view these challenges and the policies they will seek. The industry consumes about 37% of the primary energy in the United States, and is expected to grow under business-as-usual conditions. The policy scenarios are expected to find energy efficiency improvements from 7% and 17% beyond business as usual by 2020 for the Moderate and Advanced scenarios, respectively. Carbon dioxide emissions would grow to 578 Mt C by 2020 (452 Mt C in 1990) under the BAU-scenario. In the policy scenarios, the emissions would be 10% and 29% lower under the Moderate and Advanced scenarios, respectively. CHP is expected to contribute to an additional reduction in CO_2 emissions by 2020, of almost 10 Mt C for the Moderate scenario and almost 40 Mt C in the Advanced scenario. The energy efficiency opportunities are found throughout industry. The characteristics of decision-makers vary widely. Therefore, an integrated policy framework accounting for the different characteristics of decision-makers, technologies and sectors is necessary. The framework may include a variety of programs, as discussed above.

Future research needs are highlighted, both with respect to modeling as well as policy analysis and evaluation. The main issues are technology representation and efficiency trends in the model, and the need for detailed evaluation of the effects and cost-effectiveness of industrial energy efficiency policies.

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